Improving Soil Properties of Red Acid Soil to Increase Growth and Yield of Pineapple (Ananas comusus L. Merr.) by Liming and Compost, in Lampung, Indonesia

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（インドネシア国ランポン州におけるパイナップル（*Ananas comusus* L. Merr.）の生育向上を目的とした石灰と堆肥の施用による赤色酸性土壌の改良）

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SUMMARY

Red soils classified by the USDA are distributed in tropical and subtropical zones around the world and occupy 6.4×10^9 ha or 45% of the world's land area. The total area of red soils in Indonesia is 51 million ha or 27% of the land area. These soils are divided into four major groups according to the Indonesian soil classification: Red Yellow Mediterranean soil, Latosol, Red Yellow Podzolic soil, and Lateritic soil. Podzolic soil, found on acidic volcanic tuff in Lampung, Indonesia, can be classified into Oxic Dystropepts, Sumbritropepts, Tropohumults, and Paleodults. They are marginal soils that have many problems. Their characteristics are their low pH and low organic matter, poor nutrients, high aluminum (Al) content and low base saturation, and low cation exchange capacity and sensitivity to erosion. Such problems in red soils have commonly been improved by the application of compost / organic matter, dolomite, *etc*.

Compost is derived from organic matter that has been decomposed and is relatively stable due to aerobic microbial degradation. Compost is very important for improving soil fertility and for helping to increase plant productivity. It is rich in nutrients and organic matter. Many factors are affected by the provision of compost in the soil, including the enhancement of nutrient levels, as it contains N, P, K, Ca, Mg, and S. Compost is rich in alkaline cations, and thus, also has a liming effect that can increase the soil pH.

Dolomite is limestone which is commonly applied to increase the soil pH. It is used not only for liming, but also as fertilizer due to the Ca and Mg elements contained in it which are needed to improve soil fertility and increase plant productivity. An increase in pH due to dolomite application also increases the availability of nutrients and can reduce the aluminum in the soil. This is a positive influence because it can reduce the effects of Al toxicity which can interfere with

plant growth. The applications of compost and dolomite will improve soil properties and can increase plant productivity.

In this dissertation, there are three research, included: The first, on the use of compost as an organic material combined with chemical fertilizers to improve soil properties, both chemical and physical soil to improve growth and increase pineapple production. The second is research on giving dolomite lime to increase soil pH was also carried out to increase the availability of macro nutrients and to suppress the element of Fe which, if too high, will be toxic. The third, research that combines lime and compost was also carried out to determine the effect of these two treatments on soil pH, as well as the relationship between soil pH and the availability of macro and toxic aluminum nutrients.

This experiment was conducted at the Research and Development Department (R&D Dept.), PT GGP, Lampung, Indonesia (about 46 meters above sea level with coordinates of 4°49’27’’S and 105°13’55’’E) from November 2015 to January 2017. For the first experiment, compost application was carried out in pineapple plant areas, while liming experiments and a combination of compost and dolomite were carried out in a green house.

The first results showed that compost could improve the chemical and physical properties of soil, which were significantly different from those of the control. The application of compost could not increase the nutrient uptake in the leaves of pineapples, but the foliar fertilizer application was effective enough. The pineapple yield was seen to increase with the application of a compost dose of 50 t ha^{-1} compared with the control, but the yield was no different from that with a compost dose of 25 t ha^{-1}. However, the application of a compost dose of 50 t ha^{-1} consistently produced a higher yield compared to the other treatments except for K25P60 treatment. The application of the compost dose of 25 t ha^{-1} enabled a reduction in the use of chemical fertilizer applied by foliar spray by 40% with no loss in yield.

The Second experiment showed that application of dolomite was seen to increase the soil pH significantly. Increased the soil pH can increase the potassium (K), calcium (Ca) and magnesium (Mg) in the soil and decreased the iron (Fe) considerably. Increased those soil chemicals and decreasing the iron in the soil can improve the growth of the pineapple. In particular, the leaf area of the pineapple plant increased significantly. The other parameters also increased, but not significantly.

The third research showed that the application of dolomite and compost, respectively, can significantly increase the soil pH. The combination of compost and dolomite can increase the soil pH significantly. The pattern of nutrient changes in the soil, such as Ca and Mg, showed a good linear correlation with the changes in the soil pH, but K and Na did not show a good relationship. The exchangeable aluminum in the soil showed a good quadratic correlation with the soil pH for red acid soils.

概要

USDA で分類される赤色土は、世界中の熱帯および亜熱帯に分布し、6.4×109 ヘクタール、つまり世界の陸地の 45%を占めている。インドネシアの赤色土の総面積は 5100 万 ha で、土地面積の 27%である。これらの土壌は、インドネシアの土壌分類に従って、4 つの主要なグループに分類される。赤黄色の地中海土壌、ラトソル、赤黄色ポドゾル土壌、ラテライト土壌である。インドネシアのランポン州の酸性火山性凝灰岩に見られるポドゾル土は、ジストロペプト、サンブリトロペプト、トロポフマルト、およびパレオダルトに分類でき、それらは多くの問題を抱えている限界土壌である。それらの特徴は、低 pH と低有機物含有量、貧弱な栄養素、高アルミニウム（Al）含有量と低塩基飽和、および低カチオン交換容量と侵食に対する感度です。赤色土のこのような問題は、通常、堆肥/有機物、ドロマイトなどを適用することで改善されている。

堆肥は、分解された有機物に由来し、好気性微生物による分解のために比較的安定している。堆肥は、土壌の肥沃度を向上させ、植物の生産性を高めるのに非常に重要で、栄養素や有機物が豊富である。堆肥には N、P、K、Ca、Mg、S が含まれているため、土壌中の堆肥の供給には多くの要因が影響する。これには、栄養素レベルの向上と、土壌 pH を上昇させる効果が期待できる。

ドロマイトは石灰岩で、土壌 pH を上げるためによく使用される。土壌のライミングだけでなく、土壌の肥沃度を高め、植物の生産性を向上させるために必要な Ca と Mg 元素供給のための肥料としても使用される。ドロマイトの適用による pH の上昇は、

栄養素の利用可能性も高め、土壌中のアルミニウムを減らすことができるため、作物生産に良い効果が期待できる。

この論文には、3 つの研究内容から構成される。初めの研究は、堆肥を有機材料として使用し、化学肥料と組み合わせて土壌の特性と作物の生産性を改善することを目的としている。2 番目の研究は、土壌 pH を上げるためにドロマイト石灰を与えることに関する実験である。これは、主要栄養素の利用可能性を高め、高すぎると毒性になる Fe の元素を抑制するために行なった。3 番目の研究は、石灰と堆肥を組み合わせた実験であり、これら 2 つの処理が土壌の pH に及ぼす影響と、栄養塩類および有毒アルミニウムイオンへの影響を検討するものである。これらの実験は、2015 年 11 月から 2017 年 1 月までの期間に、インドネシアのランポン州にある PT GGP の研究開発部門（R&D 部門）で実施した。

最初の研究結果は、堆肥の施用が土壌の化学的および物理的特性を改善することを示した。元肥として堆肥を施用してもパイナップルの葉の栄養摂取量を増加させることはできなかったが、化学肥料の葉面散布施肥は十分効果的であった。パイナップルの収量は、50 t ha^{-1} の堆肥量を施用すると、他の処理区や対照区と比較して、ほぼ一貫して高い収量が得られたが、25 t ha^{-1} の堆肥量の場合と有意な差は見られなかった。一方、25 t ha^{-1} の堆肥を施用すると、葉面散布によって施用される化学肥料の使用量を 40%削減しても、収量を損なうこがなかった。

2 番目の実験では、ドロマイトを適用すると土壌の pH が大幅に上昇することが明らかになった。土壌 pH が上昇すると、土壌中のカリウム（K）、カルシウム（Ca）、

マグネシウム（Mg）が増加し、鉄（Fe）が大幅に減少し、パイナップルの成長を改善することができた。このように土壌の理化学性が向上したことによって、パイナップルの成長は改善され、とくに、パイナップルの葉面積が著しく増加することを明らかにした。

3 番目の研究では、ドロマイトと堆肥をそれぞれ施用すると、土壌 pH が大幅に上昇することが明らかになった。 とくに、土壌ｐH は Ca や Mg などの土壌栄養素と明瞭な正の線形関係が見られたものの、K と Na には良好な相関関係がなかった。 一方、土壌ｐH が上昇すると交換性アルミニウムが急激に減少する傾向が見られた。土壌ｐH は、ドロマイトと堆肥のそれぞれの施用量を変数とする線形式（R^2=0.931）で表され、目標とする土壌ｐH に必要なドロマイトと堆肥の施肥量を推定することを可能にした。

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CHAPTER I

GENERAL INTRODUCTION

Introduction

Red soil in Indonesia is classified into four major groups according to the Indonesian soil classification, namely: Red Yellow Mediterranean Soils, Latosol, Red Yellow Podzolic Soils and Lateritic Soils. Podzolic soils in acidic volcanic tuffs in Lampung, Indonesia, were classified as Oxic Dystropepts, Sumbritropepts, Tropohumults and Paleodults (Buurman, 1980).

This type of soil is very widespread in the world, both in tropical and sub-tropical regions and almost reaches 45% of the total land area worldwide (Wang, 2016). Meanwhile in Indonesia, red soil has a distribution area of more than 25% of the total area (Prasetyo and Suriadikarta, 2006).

Soils of this type are usually also widely distributed in humid tropic areas which have very high rainfall (Buurman, 1980). The nutrient content in the soil is usually very low due to very intensive leaching, and usually very low organic matter due to rapid decomposition (Prasetyo and Suriadikarta, 2006). Red soil is a marginal soil that has many problems, especially in Indonesia. The characteristics of this soil are usually low in nutrients, especially P and bases cations such as Ca, Mg, Na and K are also low. Low cation exchange capacity, high levels of aluminum and sensitivity to erosion (Buurman, 1980; Sarno et al., 2004).

The main limiting factor for this soil is the very low soil pH due to the intensive leaching process, besides that the soil organic matter is very low due to the very fast decomposition (Prasetyo, 2006; Cahyono et al., 2019).

Soil pH greatly affects the growth of various types of plants. Soil pH controls soil fertility, both chemical and biological soil, availability of nutrients in the soil and the presence of toxic micro elements. Low soil pH will result in deficiencies of calcium (Ca), phosphorus (P), magnesium (Mg) and possibly also molybdenum (Mo) (Uchida and Hue, 2000). Liming on acid soils is generally carried out to reduce Al toxicity and is believed by various soil scientists to be the first step to maintaining nutrient balance (Brown and Stecker, 2003).

Dolomite is a lime material commonly used to increase soil pH (Peters et al., 1996). This material can not only increase soil pH but also add nutrients to calcium (Ca) and magnesium (Mg) which are needed by large amounts of plants to improve soil fertility and increase plant productivity (Mite et al., 2010). The increase in pH due to the application of dolomite will increase the availability of nutrients and can reduce toxic aluminum in the soil (Upjohn et al., 2005).

Soil organic matter is a collection of various complex organic compounds that are undergoing or have undergone a decomposition process, either in the form of humus resulting from humification or mineralized inorganic compounds, including the heterotrophic and autotrophic microbes involved. In the management of soil organic matter, the source can come from the application of organic fertilizers in the form of manure, green manure, compost, and biological fertilizer (Hanafiah, 2005). This organic material has several important roles in the soil, namely as a provider of nutrients (especially nitrogen, phosphorus, and sulfur), increasing cation exchange capacity, as a food source for microorganisms, and the main function of this organic material as a soil repairer. This is what makes organic matter important for the soil.

Compost is organic material which will increase the availability of nutrients in the soil when given into the soil and the effect can be direct or indirect. The direct effect is the addition of nutrients contained in the compost, while the indirect effect is increasing microbial activity in the soil, improving soil structure and increasing water holding capacity (Banuwa et al., 2020; Zaki et al., 2020). Compost releases nutrients very slowly and indirectly, therefore the supply of nutrients from compost to meet the nutritional needs of plants, especially in critical periods, is not sufficient. Usually the combination of providing compost with inorganic fertilizers is a good strategy to increase productivity (Duong, 2013; Adugna, 2016).

In this study, research on the use of compost as an organic material combined with chemical fertilizers to improve soil properties, both chemical and physical soil, is carried out to improve growth and increase pineapple production. The second, research on adding dolomite lime to increase soil pH was also carried out to increase the availability of macro nutrients and to suppress the element of Fe which, if too high, will be toxic. The third, research that combines lime and compost was also carried out to determine the effect of these two treatments on soil pH, as well as the relationship between soil pH and the availability of macro and toxic aluminum nutrients.

This experiment was conducted at the Research and Development Department (R&D Dept.), PT GGP, Lampung, Indonesia (about 46 meters above sea level with coordinates of 4°49’27’’S and 105°13’55’’E).

The total number of studies aimed at increasing the fertility of red acid soil consists of three studies. The title and implementation time are as follows:

1. Effects of compost on soil properties and yield of pineapple (*Ananas comusus* L. Merr.) on red acid soil, Lampung, Indonesia, which was conducted in pineapple plant areas, from January 2016 to January 2017.

2. Influence of liming on soil chemical properties and plant growth of pineapple (*Ananas comusus* L. Merr.) on red acid soil, Lampung, Indonesia, which was conducted from November 2015 to April 2016.

3. Patterns of nutrient availability and exchangeable aluminum affected by compost and dolomite in red acid soils in Lampung, Indonesia. This research combined of compost and dolomite was conducted from February 2016 to May 2016.

Research Objectives

The objectives of these studies are:

1. To determine the effects of compost application on the chemical and physical properties of the soil, and to determine the effects of reducing the doses of foliar chemical fertilizers on the pineapple yield on red acid soil.

2. To determine the effects of liming on the soil pH, the Fe in the soil and the growth of the pineapple plant.

3. To know the effects application of dolomite and compost on increasing soil pH, availability of nutrients and decrease of exchangable aluminum in the soil and the relationship the Ca, Mg, K, Al with pH.

CHAPTER II

Effects of Compost on Soil Properties and Yield of Pineapple (*Ananas comusus* L. Merr.) on Red Acid Soil, Lampung, Indonesia

Introduction

Red soil is very widespread in tropical and sub-tropical regions throughout the world and occupies more than 45% of the total land area of the world (Wang, 2016). Whereas in Indonesia, ultisol soil which is red soil has a distribution of up to 25% of the total land area (Prasetyo and Suriadikarta, 2006). The nutrient content in that soil is generally very low due to very intensive leaching, and the organic matter content is also low because the decomposition process occurs very quickly. Increasing productivity in this soil type can be done by liming or through the application of organic matter (Prasetyo and Suriadikarta, 2006; Cahyono et al., 2019).

Compost is one type of organic matter; it can increase the nutrient availability and its effects can be direct or indirect. The direct effect is the addition of nutrients from the compost, while the indirect effect is the increase in microbial activity, an improvement in the soil structure and an increase in the water holding capacity (Banuwa et al., 2020 and Zaky et al., 2020). Compost releases plant nutrients very slowly and indirectly, which are absorbed by the plant. Therefore, the plant cannot access the amount of nutrients needed in the critical yield period only by compost application. Hence, an approach for compost application in combination with inorganic fertilizer is a good strategy for increasing productivity (Duong, 2013; Adugna, 2016). On the other hand, a decrease in land quality, an increase in soil acidity and environmental pollution will occur due to the excessive and long-term use of chemical fertilizers (Ning et al., 2017).

A pineapple plantation of the Great Giant Pineapple Company (PT GGP) is located in Lampung, Indonesia where most of the soil consists of red-yellow podzolic (Cahyono et al., 2018; Komariah et al., 2008). The results of a soil analysis in the laboratory showed that the soil pH and the organic matter content at this plantation were very low and that the nutrient availability was also very low. With these poor soil characteristics, a large amount of foliar fertilizer tended to be applied.

One of the solutions for improving the soil properties and reducing the chemical fertilizer is to increase the amount of compost usage from cattle manure produced by the compost plant of PT GGP. Various studies on the role of compost and its soil properties have been done, but the researches associated with decreasing the usage of foliar chemical fertilizer are still very rare, especially for pineapple crops on red acid soil. The objectives of this research are to determine the effect of compost application on the chemical and physical properties of the soil, and to determine the effect of reducing the doses of foliar chemical fertilizers on the pineapple yield on red acid soil.

Materials and Methods

Materials and experimental design

This experiment was conducted at the Research and Development Department (R&D Dept.), PT GGP, Lampung, Indonesia (about 46 meters above sea level with coordinates of 4^{0}49’27’’S and 105^{0}13’55’’E) for a period of 12 months, from January 2016 to January 2017. The nutrient contents of the soil and the compost are shown in Table 1.

Table 1. Characteristics of initial soil and compost

Properties	Initial soil	Compost
pH	4.76	7.20
Total C (wt %)	1.59	21.60
Total N (wt %)	0.16	1.68
C/N ratio	9.93	12.86
P (g kg^{-1})	0.01	2.60
K (g kg^{-1})	0.10	18.13
Ca (g kg^{-1})	0.22	21.50
Mg (g kg^{-1})	0.12	5.26

The compost was obtained from the compost plant at PT GGP; the raw materials originated from cow dung, bromelain waste and bamboo chopping through a composting process that lasted about one month (Figure 1).

Figure 1. Compost material can be used to experiment

The soil texture at this location is sandy clay with 56.4 % sand, 6.6 % silt and 37.0 % clay. The physical properties of the initial soil are shown in Table 2.

Table 2. Physical properties of initial soil

Properties		Initial soil
Bulk density (g cm^{-3})		1.24
Particle density (g cm^{-3})		2.31
Porosity (vol %)		46.30
Texture (wt %)	Sand	56.40
	Silt	6.60
	Clay	37.00

Seed materials were used from the suckers of pineapple which were taken from the pineapple plantation of PT GGP, Lampung, Indonesia. The seedlings were selected from the suckers picked from the slips of pineapple plant (Figure 2).

Figure 2. Sucker for planting material

The compost was applied manually in a row, one week before planting (Figure 3).

Figure 3. Compost in rows which are applied manually

The rate of compost application was determined according to the treatment details in Table 3.

Table 3. Details of each treatment

Treatment	Compost ($t\ ha^{-1}$)	Standard fertilizer (%)	Reduction in fertilizer (%)
K0P100	0	100	0
K0P80	0	80	20
K0P60	0	60	40
K25P100	25	100	0
K25P80	25	80	20
K25P60	25	60	40
K50P100	50	100	0
K50P80	50	80	20
K50P60	50	60	40

Base fertilizer was applied one day before planting on the same row with the same amount for all treatments. The base fertilizer consisted of diammonium phosphate (DAP), potassium chloride (KCl) and kieserite ($MgSO_4.H_2O$). Another type of fertilizer was applied manually (by hand application) one month after planting; it consisted of ZA ($(NH_4)_2SO_4$) and K_2SO_4 for all treatments. The foliar fertilizer was applied two months after planting, and was continued every month following the details given in Table 4. The treatments of fertilizer reduction were started at this stage.

Table 4. Treatments for fertilizer reduction

Treatment	Fertilizer	Foliar fertilizer				Total (kg ha^{-1})
		1st	2nd	3rd	4th	
P100	Urea	75	75	75	100	325
	K_2SO_4	50	50	75	100	275
P80	Urea	60	60	60	80	260
	K_2SO_4	40	40	60	80	220
P60	Urea	45	45	45	60	195
	K_2SO_4	30	30	45	60	165

A factorial experiment was arranged in a randomized block design with two factors and three replications. The first factor was the rate of compost application which consisted of three doses: K0 (no compost), K25 (compost 25 t ha^{-1}) and K50 (compost 50 t ha^{-1}), and the second factor was the reduction of fertilizers which consisted of three steps of decrease: P100 (100% of the standard fertilizer or 0% reduction in fertilizer), P80 (80% of the standard fertilizer or 20% reduction in fertilizer) and P60 (60% of the standard fertilizer or 40% reduction in fertilizer). Details of the treatments are presented in Table 3. The plot area was ploughed to be 30 cm in depth and marked out to obtain individual plot sizes of 3×5.5 m.

Data collection and analysis

Soil sampling and an analysis were conducted once at the beginning and again four months after planting to understand the changes in the soil properties. Soil was sampled at a depth of 0-20 cm and a composite of three samples per treatment was made. The soil observation consisted of chemical properties, namely, (1) the pH was measured by a pH meter-Mettler Toledo, (2) the organic C-content was determined by the Walkley and Black method, (3) an N analysis was done by the Kjeldahl method, (4) a P analysis was done by the P Bray-1 method and (5) an analysis of K, Ca and Mg was performed by extraction with ammonium acetic pH 7 and a reading by Atomic Absorption Spectrofotometry (AAS)-GBC.

The physical properties of the soil consisted of the following: (1) the bulk density was measured by the core method (Figure 4), and the soil sampling technique was carried out by taking one soil sample per treatment and three replications, thus, a total of 27 samples (9 treatments×3 replications), (2) the particle density was analyzed by the pycnometer method, (3) the porosity was calculated using the formula for bulk density and particle density and (4) the soil hardness was measured by a penetrograph (Figure 5).

Figure 4. Core method

Figure 5. Penetrograph

Leaf sampling and an analysis were done seven months after planting to determine the effect of the treatment on the nutrient uptake in the leaves of the pineapple. Leaves were sampled by taking one leaf (the longest leaf) per plant and a composite of nine leaves per treatment (no replications). An analysis of (1) nitrogen (N) was done by the Kjeldahl method and (2) potassium (K) was done by the wet ashing method and a reading by AAS. The fruit yield was obtained by multiplying the average fruit weight by the population at harvest time.

Statistical analysis

All data collected from the three replications were subjected to an analysis of variance (ANOVA) using the Tukey Test and 95.0 % confidence to determine the differences among the treatments.

Results and Discussion

Almost 90 % of the fertilizer was given through foliar spray and only basic fertilizers and the first fertilization were supplied through the soil. The purpose of the application of compost in the soil was to reduce the frequency and the amount of fertilizer given through the leaves (Figure 6).

Figure 6. Foliar spray by machinery

This experiment was to determine not only the effect of the compost application on the chemical and physical properties of the soil, but also its effect on the use of foliar fertilizer which is the most commonly applied fertilizer for pineapple plants.

Effects of compost on soil chemical properties

The chemical properties of the soil in the compost treatments four months after planting are presented in Table 5.

Table 5. Chemical properties of soil four months after compost application

Chemical	Dose of compost (t ha^{-1})		
Properties	0 (K0)	25 (K25)	50 (K50)
pH H2O	4.93a	5.68b	5.88b
C (wt %)	1.50a	2.02b	2.25b
N (wt %)	0.14a	0.18b	0.22b
P (g kg-1)	0.024a	0.028a	0.032a
K (g kg^{-1})	0.05a	0.10b	0.13b
Ca (g kg^{-1})	0.26a	0.62b	0.84b
Mg (g kg^{-1})	0.17a	0.27b	0.32b

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

There were significant differences between the soil pH of the compost plots (K25 and K50) and the plot with no compost (K0). The soil pH increased significantly in the plots applied with compost (K25 and K50), at doses of 25 t $ha^{-1}$and 50 t ha^{-1}, compared to the control (K0) and the initial condition (Table 1), because the pH value of the compost itself tended to be around neutral (pH 7.2), higher than that of the initial soil. The mineralization of compost will release basic cations, which are alkalines, so that the application of a large amount of compost, even done continuously, will increase the soil pH (Adugna 2016). The application of the compost dose of 50 t ha^{-1} caused the soil pH to increase 0.20 points more than the compost dose of 25 t ha^{-1}, but the difference was not significant (Table 5).

The C-organic contents of the soil also increased with the compost application. The application of compost at doses of 25 t ha^{-1} and 50 t ha^{-1} (K25 and K50) significantly increased the C-organic contents compared to the control (K0), whereas that of the control plot slightly decreased in comparison with the initial condition (1.59 wt %). Furthermore, the C-organic content of the compost plot with the dose of 50 t ha^{-1} (K50) was higher than that of the compost plot with the dose of 25 t ha^{-1} (K25). However, no significant difference was seen between these two compost plots. In Table 1, it can be seen that the C-organic content in the compost was already high (21.60 wt %), so that when the compost was applied to the soil, the soil organic carbon will increase. Bouajila and Sanaa (2011) reported that the application of compost from manure and household waste resulted in a significant increase in organic carbon with the compost treatment being the most efficient. Their results showed that the application of 120 t ha^{-1} of household waste compost and manure improved the organic carbon (1.74% and 1.09%, respectively) compared with the control (0.69%).

The nitrogen (N) in the soil also increased with the compost application. The application of compost with the dose of 25 t ha^{-1} (K25) increased the nitrogen content in the soil significantly compared with the control. The nitrogen in the compost plot with the dose of 50 t ha^{-1} (K50) was higher than that with the dose of 25 t ha^{-1} (K25). However, no significant difference was seen between these two compost plots. Bouajila and Sanaa (2011) reported that the application of compost concentrations (40 and 120 t ha^{-1}) resulted in a significant increase in the nitrogen in the soil. Hernandez (2016) reported that the application of compost can increase the nutrients required the by plant, including nitrogen, after the planting of a lettuce crop in the second cycle.

The available P increased slightly in all the compost treatments with the compost doses of 25 t ha^{-1} (K25) and 50 t ha^{-1} (K50) compared to the control (K0).

All the parameters of the exchangeable cations, such as potassium (K), calcium (Ca) and magnesium (Mg), significantly increased with the compost applications of 25 t ha^{-1} (K25) and 50 t ha^{-1} (K50) compared to the control (K0). Furthermore, these exchangeable cations of compost plot K50 were higher than those of compost plot K25. However, no significant difference was seen between these two compost plots. This means that compost was very useful for plants as a source of exchangeable cations. Adugna (2016) expressed that the mineralization of compost would release many nutrients into the soil, such as potassium, calcium and magnesium, so that the nutrients would be greatly increased. Sarwar (2010) reported, the application of green compost revealed that increased soil pH and EC. Moreover, Mineral nutrients (Ca, Mg, K, P, Cl) of the soil also increased by the addition of green compost.

Effects of compost on physical properties of soil

The parameters for the physical properties of the soil are shown in Table 6. There was no influence on the physical properties of the soil among the treatments of foliar fertilizer reduction because only the fertilizer applied by the foliar spray was reduced.

Table 6. Physical properties of soil four months after planting

Dose of Compost (t ha^{-1})	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Porosity (vol%)
0 (K0)	1.14**a**	2.40**a**	52.50**a**
25 (K25)	1.05**ab**	2.39**a**	56.10**ab**
50 (K50)	0.97**b**	2.38**a**	59.20**b**

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

The bulk density has an apparent tendency to decrease with an increase in the dose of the compost application. The lowest bulk density appeared with the treatment of the highest compost application with a dose of 50 t ha^{-1} (K50), which was significantly higher than the control (no compost) (K0), but not significantly different from the lower compost application with a dose of 25 t ha^{-1} (K25).

On the other hand, the parameters for the particle density were not significantly different among all the treatments, because it takes too long for the added compost to change to humus which is a constituent of soil. The parameter of porosity was obtained by calculating the bulk density and the particle density. This parameter also clearly shows that compost treatment can increase soil porosity. The highest porosity was attained by the treatment of the highest compost application with a dose of 50 t ha^{-1}(K50), which was significantly higher than the control, but not significantly different from the lower dose of 25 t ha^{-1} (K25). Brown and Cotton (2011) observed that an increasing rate of compost decreased the bulk density. The bulk density indicates an increase in pore space and was indicative of improved soil tilth. In this respect, compost increases the portions of meso- and macro-pores because an improved aggregation and stabilization of the soil were significantly initiated by various soil organisms (Liu et al. 2007).

The application of compost could also decrease the soil hardness in the root zone (at a depth 0-20 cm from the soil surface) (Table 7).

Table 7. Soil hardness four months after planting

Rate of compost ($t\ ha^{-1}$)	Soil hardness (psi)
0	1.63**a**
25	0.64**b**
50	0.66**b**

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

The applications of the compost doses of 25 t ha^{-1} (K25) and 50 t ha^{-1} (K50) show significantly different levels of soil hardness compared with the control, but they were not significantly different. This means that compost application can improve the physical properties of the soil.

Applying compost can increase in organic matter, and furthermore can improve aggregation, water-holding capacity, hydraulic conductivity, total porosity, resistance to water and wind erosion and lowers bulk density and the degree of compaction (Celix et al., 2004; Leroy et al., 2008).

Effects of compost and fertilizer reduction on leaf uptake

Nutrient uptake in the leaves of the pineapple was different among treatments. The application of compost on the soil and the foliar fertilizer will improve the nutrient contents in the leaves.

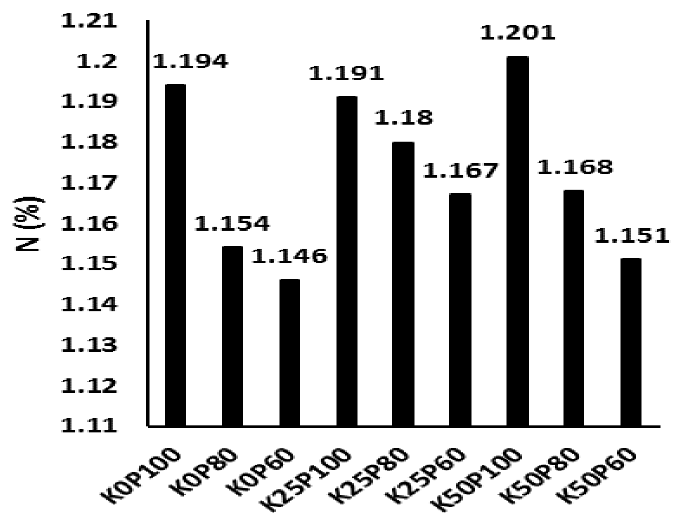

Figure 7. Effect of compost and fertilizer reduction on nitrogen in the leaves

Figure 7 shows that the highest levels of nitrogen uptake in the leaves are with treatments K50P100 (compost 50 t ha^{-1}, no fertilizer reduction), followed by K0P100 (no compost, no fertilizer reduction) and K25P100 (compost 25 t ha^{-1}, no fertilizer reduction). On the other hand, the lowest levels of nitrogen uptake in the leaves were with treatments K0P60 (no compost, fertilizer reduction 40%), K50P60 (compost 50 t ha^{-1}, fertilizer reduction 40%) and K0P80 (no compost, fertilizer reduction 20%).

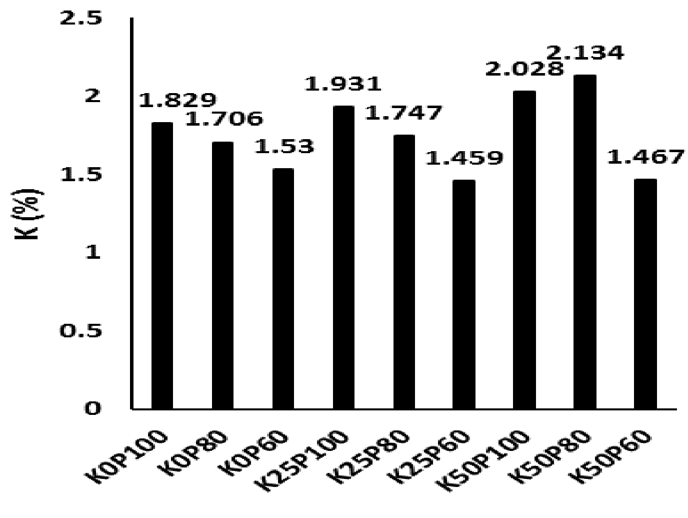

Figure 8. Effect of compost and fertilizer reduction on potassium in the leaves

Figure 8 shows that the highest levels of potassium uptake in the leaves were with treatments with higher fertilizer doses, namely, K50P80 and K50P100, and then K25P100 and K0P100. They were all higher than the treatments with other fertilizer doses. At reduced fertilizer doses of 60% or 40%, the lowest leaf uptake was observed. An increase in the compost dose did not increase the nutrient uptake in the leaf. This shows that the application of fertilizer through the leaves was still effective for increasing the nutrient uptake in the leaves compared to compost applications. This means that foliar fertilizer supplied through the leaves can effectively increase the nutrient uptake, while compost application does not affect the increase in nutrient uptake.

The leaves of the pineapple plant can absorb nutrients through the cuticles, and nutrients such as nitrogen, potassium, iron, zinc and boron were readily translocated to the whole plant (Malezieux and Bartholomew, 2003).

Effects of treatment on plant growth of pineapple

The treatment effect on root weight was shown in Table 8, where there were no significant differences in root weight among the treatments of compost doses of 25 t ha^{-1} and 50 t ha^{-1} under all foliar fertilizer reduction treatments (P60, P80, and P100). While, it was also seen that the root weights of the treatments without compost (K0) were not significantly different from the treatments of compost 25 and 50 tons ha^{-1} (K25, K50) under the treatments with reducing foliar fertilizer less than 40 % (P80 or P100). However, under the reduction of fertilizer 40%, the root weight of the treatment (K0P60) under no compost application was significantly lower than those of the treatments of compost doses of 25 t $ha^{-1}$and 50 t ha^{-1} (K25P60 and K50P60). These results could conclude that application of 25 t ha^{-1} was able to provide a good root and also reduce 40% foliar fertilizer. It has become a general consensus that low organic matter in the soil will cause growth and root health to be disrupted (Stirling, 1999).

Table 8. The effect of treatment on root weight

treatment	compost (t ha-1)	fertilizer (%)	fertilizer reduction (%)	root weight (kg)
K50P100	50	100	0	64.4a
K25P60	25	60	40	63.3a
K50P80	50	80	20	62.7a
K50P60	0	60	40	61.5a
K0P80	25	80	20	60.9a
K25P80	50	80	20	60.4a
K0P100	25	100	0	58.6a
K25P100	0	100	0	57.1a
K0P60	0	60	40	46.5b

Note: Means that do not share same letter are significantly different

The treatment effect on plant weight was also shown in Table 9, where in the treatment of K0P60, the plant weight was the least and was significantly different from the treatment of K50P100. Increase of foliar fertilizer application to 80% and 100% of standard could improve plant weight of treatments (K0P80, K0P100) under no compost application, but not significantly. Likewise, the application of compost doses of 25 and 50 t ha^{-1} also increased plant weight, but not significantly. However, it could be concluded at least that application of compost 25 t ha^{-1} was able to provide a good plant growth and also reduce 40% foliar fertilizer.

Beside, compost application can release nutrients; compost can stimulate root growth by the presence of humic substances released by the decomposing organic matter. These substances exhibit a beneficial effect on root proliferation and plant growth (Nardi et al., 2002). Adding cow dung compost on soil significantly increased by 33.1– 48.5 %, the number of leaves, and the stem diameter of Moringa oleifera (Haouvanga et al., 2017)

Table 9. The effect of treatment on plant weight

Treatment	compost (t ha^{-1})	fertilizer (%)	fertilizer reduction (%)	plant weight (kg)
K50P100	50	100	0	2917a
K25P80	25	80	20	2680ab
K50P60	50	60	40	2627ab
K0P100	0	100	0	2627ab
K25P100	25	100	0	2610ab
K50P80	50	80	20	2540ab
K25P60	25	60	40	2353ab
K0P80	0	80	20	2300ab
K0P60	0	60	40	2100b

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

Effects of treatment on pineapple yield

All treatments of compost application could increase the yield compared to no compost treatments (Table 10). In particular, the treatment of compost application of 25 t ha^{-1} and a fertilizer reduction of 40% (K25P60) attained the highest yield among all treatments, and showed a significantly higher yield of more than 10% compared to all treatments of no compost application (K0P100, K0P80 and K0P60). Furthermore, the other treatments of compost application, except for K25P60, showed a higher yield compared to all treatments of no compost application, but not significantly. From Table 10 it can be seen that all compost treatments combined with foliar fertilizer treatments produce higher production compared to without compost. Increasing the dose of foliar fertilizer in non-compost treatment (K0P60, K0P80 and K0P100) did not significantly affect production. This is due to the condition of pineapple plant roots that are not good so that the effect of fertilizer does not look real.

Table 10. The effect of treatment on yield of pineapple

Treatment	Compost ($t\ ha^{-1}$)	Fertilizer (%)	Fertilizer reduction (%)	Fruit weight (kg)	Yield ($t\ ha^{-1}$)
K25P60	25	60	40	1.70a	110.4 a
K50P100	50	100	0	1.67ab	108.5 ab
K50P80	50	80	20	1.64ab	106.9 ab
K50P60	50	60	40	1.64ab	106.6 ab
K25P80	25	80	20	1.62ab	105.2 ab
K25P100	25	100	0	1.54ab	100.1 ab
K0P60	0	60	40	1.51 b	98.0 b
K0P100	0	100	0	1.47 b	95.8 b
K0P80	0	80	20	1.44 b	93.7 b

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

Conclusion

Compost could improve the chemical and physical properties of soil, which were significantly different from those of the control. The application of compost could not increase the nutrient uptake in the leaves of pineapples, but the foliar fertilizer application was effective enough. The pineapple yield was seen to increase with the application of a compost dose of 50 $t\ ha^{-1}$ compared with the control, but the yield was no different from that with a compost dose of 25 t ha^{-1}. However, the application of a compost dose of 50 t ha^{-1} consistently produced a higher yield compared to the other treatments except for K25P60 treatment. The application of the compost dose of 25 t ha^{-1} enabled a reduction in the use of chemical fertilizer applied by foliar spray by 40% with no loss in yield.

CHAPTER III

Influence of Liming on Soil Chemical Properties and Plant Growth of Pineapple (*Ananas comusus* L. Merr.) on Red Acid Soil, Lampung, Indonesia

Introduction

Red acid soil is generally distributed in humid tropical areas under high rainfall. The main constraint is usually the pH of the soil which is extremely low due to the very intensive leaching of the bases from the soil. At the same time, however, the soil conditions include a high amount of soluble micro elements (Buurman, 1980).

The soil pH affects crops in many ways. The soil pH controls soil fertility, both chemically and biologically, and the availability of nutrients and the presence of toxic chemical elements are indirect effects of changes in the soil pH. Low soil pH can potentially lead to deficiencies in calcium (Ca), phosporus (P), magnesium (Mg) and possibly molybdenum (Uchida et al., 2000). Liming is very important for improving soil acidity because soil with high acidity can disrupt plant roots in the presence of toxic nutrients and reduce the macro nutrients (Mamo et al., 2009).

The pineapple is a plant that is quite tolerant of toxic micro elements, but at some certain levels, its growth is inhibited by them. The availability of nutrients to plants is altered by the soil pH. In acidic soils, the availability of the major plant nutrients, such as nitrogen, phosphorous, potassium, sulfur, calcium and magnesium, as well as trace elements, such as molybdenum, are reduced and may be insufficient. Liming raises the pH of acidic soils and increases the availability of these nutrients. The availability of iron, manganese, copper, zinc and aluminum is increased in acidic soils. The liming of acidic soils is generally practiced to reduce the Al toxicity and is considered by many soil scientists as the first step towards providing balanced nutrition to cultivated plants (Brown and Stecker, 2003). The aim of this study is to determine the effects of liming on the soil pH, on the Fe condition in the soil and on the growth of the pineapple plant.

Materials and Methods

Materials and experimental design

This experiment was conducted at the Research and Development Department of PT Great Giant Pineapple (PT GGP), Lampung, Indonesia (about 46 meters from sea level with coordinates of $4^0$49'27''S and $105^0$13'55''E) from November 2015 to April 2016. The soil texture was sandy clay comprised of 56.4% sand, 7.1% silt and 36.5% clay. The other values were a pH level of 3.97, calcium (Ca) of 0.19 me/100 g, magnesium (Mg) of 0.32 me/100 g, natrium of 0.24 me/100 g and iron (Fe) of 177 ppm. The nutrient contents in the soil and the pH level are shown in Table 11. The soil type was classified as red-yellow podzolics or ultisols.

Table 11. Initial conditions of chemical properties of soil

pH	Ca (me/100g)	Mg (me/100g)	Na (me/100g)	Fe (ppm)
3.97	0.19	0.32	0.24	177

The liming material used in the experiment was dolomite, containing 32.0% CaO and 18.0% MgO, and the particle size was 250 μm. Seed materials were used from the crown of the pineapple which was derived from the pineapple plantation located at PT GGP, Lampung, Indonesia.

Methodology

Twenty-one polybags were prepared. Into each bag, 15 kg of soil were placed. Before the liming treatments, 55 ml of Fe-EDTA were added to all the polybags by spraying into the soil and mixing the Fe-EDTA evenly to increase the iron content in the soil (Figure 9).

Figure 9. Placement of polybags planted with pineapple plants according to treatment

The liming treatments consisted of: D0 (dolomite 0 t ha^{-1}), D1 (dolomite 1 t ha^{-1}), D2 (dolomite 2 t ha^{-1}), D3 (dolomite 3 t ha^{-1}), D4 (dolomite 4 t ha^{-1}), D5 (dolomite 5 t ha^{-1}) and C0 (dolomite 0 t ha^{-1}, no Fe-EDTA). The experiment was arranged in a completely randomized design with seven treatments and three replications. Details of the treatments and the abbreviations are presented in Table 12.

Table 12. Details of treatments

Treatment	Abbreviation
Dolomite 0 t ha^{-1}- Fe EDTA	C0
Dolomite 0 t ha^{-1}+ Fe EDTA	D0
Dolomite 1 t ha^{-1}+ Fe EDTA	D1
Dolomite 2 t ha^{-1}+ Fe EDTA	D2
Dolomite 3 t ha^{-1}+ Fe EDTA	D3
Dolomite 4 t ha^{-1}+ Fe EDTA	D4
Dolomite 5 t ha^{-1}+ Fe EDTA	D5

After the treatments were completed, the soil was incubated for 1 week before planting the pineapple plants. The polybags were placed in the Green House and the soil moisture content was maintained at the field capacity condition.

Soil and plant growth analysis

The soil samples were analyzed once at the beginning of the experiment (before treatment) and then again at the end of it (5 months after planting) to ascertain the changes in the soil properties. An initial soil analysis was done by taking representative soil samples before each treatment. One sample of soil was taken from each polybag at the end of the treatment for analysis. The measured soil parameters were (1) the soil pH, taken with a pH meter-Mettler Toledo, (2) the K, Ca and Mg, taken by extraction with ammonium acetic pH 7 and a reading with Atomic Absorption Spectrofotometry (AAS)-GBC, and (3) the Fe, taken by the DTPA method and a reading with AAS. Measuring the growth of the pineapple plant included (1) the total root weight (Figure 10), (2) the plant weight (Figure 11), (3) the leaf area of the longest leaf and (4) the leaf color by Chlorophyl meter (SPAD 502).

Figure 10. Weighing the roots **Figure 11**. Weighing the plant

Leaf sampling and an analysis were done to find the effect of each treatment on the nutrient uptake into the leaf of the pineapple plant. The K, Ca and Mg contents in the leaf were analyzed by the wet ashing method and a reading was done by AAS.

Statistical analysis

All the data collected from the three replications were subjected to an analysis of variance (ANOVA) using the Tukey Test and 95.0% confidence to determine the differences among the treatments.

Results and Discussion

Effects of treatments on soil chemical properties

The effects of the dolomite applications on the chemical properties of the soil are presented in Table 13. An increase in the dolomite dose is seen to increase the soil pH significantly.

Treatment D5 has the highest soil pH among all the treatments, while control treatments C0 and D0 have the lowest soil pH and are significantly different from treatments D3, D4 and D5, but are not significantly different from treatments D1 and D2. Dolomite is most commonly used as a liming material to neutralize soil acidity because it contains carbonate that has the effect of the neutralizing the soil pH (Upjohn, 2005). The source of the acidity (H^+) has been reduced by liming, with the following reaction:

$$CaCO_3 + 2H^+ = Ca^{2+} + CO_2 + H_2O$$

The potassium (K) content in the soil can increase with the dolomite dose. An increase in the dolomite dose will increase the availability of potassium. Dolomite, as lime, can increase the soil pH and have an indirect effect of increasing the availability of nutrients, including potassium.

Table 13. Chemical properties of soil after treatments

Treatment	pH	K(ppm)	Ca(ppm)	Mg(ppm)	Fe(ppm)
C0	4.49c	43.2b	57.8c	16.1b	183a
D0	4.43c	43.5b	41.8c	14.4b	159ab
D1	4.77bc	43.2b	192.4b	85.1ab	138bc
D2	5.01abc	44.7ab	266.5ab	110.7ab	117c
D3	5.25ab	45.8ab	323.7[a]	124.4a	104cd
D4	5.32ab	48.5ab	359.7[a]	136.4a	100cd
D5	5.58a	57.4a	373.3a	165.1a	77d

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

Table 13 shows that the potassium content of treatment D5 (dolomite dose 5 t ha^{-1}) is considerably higher than that of either C0 or D0 (control treatments). Suriyagoda (2016) showed in his research results that the application of dolomite was successful in increasing the availability of the P and K nutrients in the soil as well as the growth and yield of rice plants.

The calcium (Ca) content in the soil increased greatly with the increase in the dolomite dose. Table 13 shows that all treatments of dolomite significantly increased the Ca content more than the control treatments (C0 and D0), but that there was no significant difference in Ca between D1 and D2. This means that the application of dolomite as a liming material containing CaO can supply and increase the Ca in the soil. On the other hand, the increase in the soil pH also increases the exchangeable calcium in the soil.

The magnesium (Mg) in the soil increases significantly with the increase in the dolomite dose. Table 13 shows that treatments D3, D4 and D5 contained substantially higher levels of Mg than the control treatments (C0 and D0), but not substantially higher levels than either D1 or D2. This means that dolomite is a liming material containing MgO that can supply and increase Mg in the soil. On the other hand, the in the soil pH also increases the exchangeable calcium in the soil. Dolomite, as lime, provides the basic nutrient cations of calcium (Ca) and magnesium (Mg) (Bolan et al., 2003).

The availability of nutrients to plants is altered by the soil pH. In acidic soils, the available major plant nutrients are nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and trace elements. Liming, performed to raise the pH of acidic soil, will increase the availability of these nutrients (Brown and Stecker, 2003).

Adding dolomite or other lime material can increase the level of calcium and magnesium ions (Mamo et al., 2009). Saarsalmi et al. (2011) also showed that the amount of exchangeable calcium and the bases saturation in the ploughed topsoil increased significantly with the lime application.

Red acid soil that has very low pH may cause Fe toxicity (Aung, 2006). The dolomite treatments are seen to have greatly influenced the iron content in the soil. In other words, the application of dolomite can decrease the iron in the soil. The effect of dolomite on the iron in the soil is seen in Table 3, namely, that the iron contents of treatments D2, D3, D4 and D5 were significantly different from those of the control treatments (C0 and D0) and tended to decrease with the increase in the dolomite dose. This means that dolomite, as a source of liming, can increase the soil pH and decrease the Fe in the soil. Suriyagoda (2016) expressed that the application of dolomite in lowlands could decrease the exchangeable soil Fe^{2+} and increase the impact of iron toxicity.

Effect of treatments on leaf nutrient uptake

The nutrient uptake into the leaf is shown in Table 14. The application of dolomite enhances the nutrients of K, Ca and Mg taken into the leaf. Figures 12, 13 and 14 indicate that the highest dose of dolomite (D5) showed the highest nutrients of K, Ca and Mg in the leaf. On the other hand, the control treatments (C0 and D0) showed the lowest nutrients in the leaf. Adding dolomite as a liming material will increase the magnesium availability in the soil and the plant.

Table 14. Effect of dolomite on nutrient uptake in leaf of pineapple

Treatment	K (%)	Ca (%)	Mg (%)	Fe (ppm)
C0	1.00	0.14	0.14	304
D0	1.00	0.14	0.17	354
D1	0.92	0.20	0.23	281
D2	1.05	0.21	0.23	285
D3	1.08	0.21	0.19	212
D4	1.43	0.22	0.25	212
D5	1.58	0.26	0.25	171

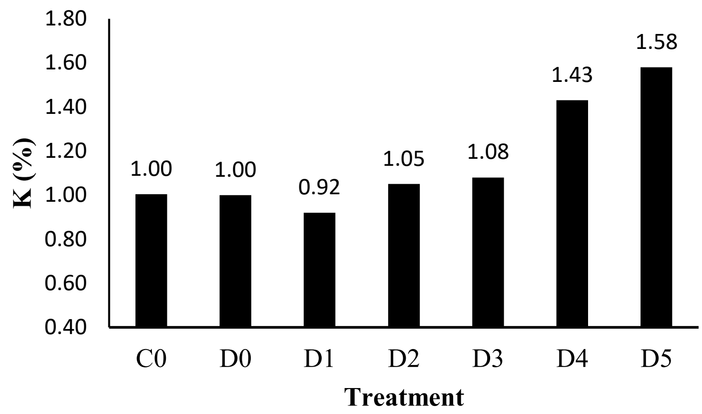

Figure 12. Effect of treatment on potassium in leaf

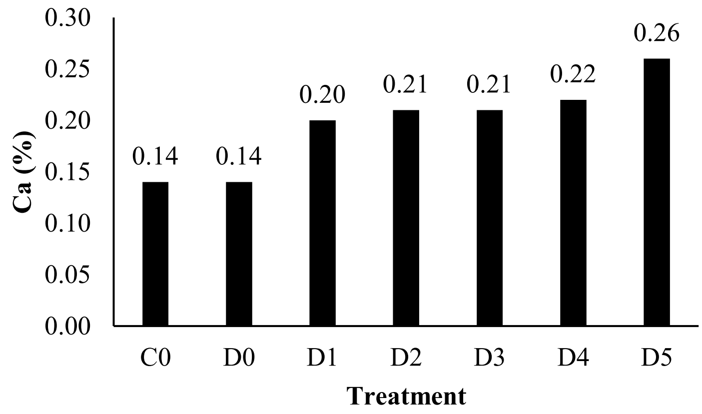

Figure 13. Effect of treatment on calcium in leaf

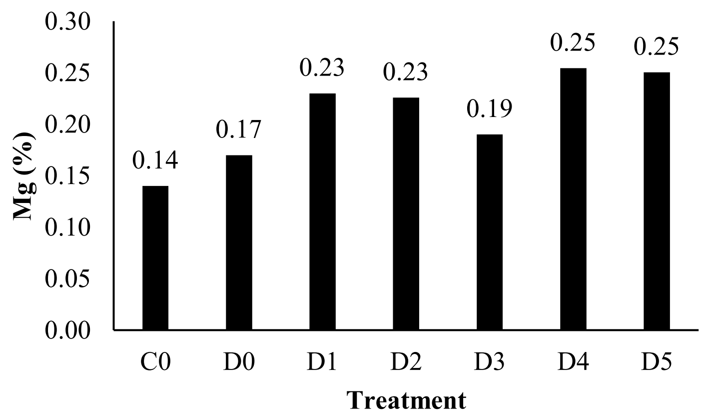

Figure 14. Effect of treatment on magnesium in leaf

Moreover, the application of dolomite tends to decrease the iron in the leaf. Table 14 shows that the Fe content of treatment D0 was the highest among all the treatments of dolomite application and that the Fe content of treatment C0 was the next highest. The Fe contents tended to decrease along with the increasing doses of dolomite.

Effect of treatments on growth of pineapple

The application of dolomite can increase the growth of the pineapple plant. The plant growth with treatments D3, D4 and D5 for the period up to 5 months after planting was higher than with the other treatments. Table 15 shows that the leaf area and the plant weight with the control treatments (C0 and D0) were lower compared to the other treatments of dolomite application. The readings for the parameter of leaf colour were also seen to be better with the dolomite treatments than with the control treatments (C0 and D0). This means that the application of dolomite can improve the growth of the pineapple plant.

Table 15. Effect of treatment on growth parameters of pineapple

Treatment	Plant weight (g)	Root weight (g)	Leaf area (cm^2)	Leaf colour (SPAD)
C0	390a	14.1a	114c	55a
D0	400a	12.4a	115c	57a
D1	397a	14.3a	119c	60a
D2	400a	15.4a	125b	61a
D3	420a	18.6a	131a	61a
D4	417a	19.2a	129ab	62a
D5	420a	17.2a	133a	60a

Note: Means that do not share same letter are significantly different, Grouping Information Using Tukey Test and 95.0% Confidence

The root of the pineapple plant also has a good appearance. Table 15 shows that a dose of dolomite can improve the root growth. A higher weight of root is seen with treatments D4, D3 and D5 compared with the other treatments (C0, D0, D1 and D2). This means that the root growth can be improved by increasing the soil pH with liming by means of dolomite. Dolomite can increase the soil pH and the nutrient availability, and consequently, can improve the plant growth of the pineapple plant. Brown and Stecker (2003) showed that the plant biomass will increase with the addition of calcium and magnesium through liming.

Conclusion

The application of dolomite was seen to increase the soil pH significantly and in different ways. Increasing the soil pH increased the potassium (K), calcium (Ca) and magnesium (Mg) in the soil and decreased the iron (Fe) considerably. Increasing those soil chemicals and decreasing the iron in the soil were found to improve the growth of the pineapple. In particular, the leaf area of the pineapple plant increased significantly. The other parameters also increased, but not significantly.

CHAPTER IV

Patterns of Nutrient Availability and Exchangeable Aluminum Affected by Compost and Dolomite in Red Acid Soils, Lampung, Indonesia

Introduction

Red soils classified by the USDA are distributed in tropical and subtropical zones around the world and occupy 6.4×10^9 ha or 45% of the world's land area (Wang, 2016). The total area of red soils in Indonesia is 51 million ha or 27% of the land area (Notohadiprawiro, 1986). These soils are divided into four major groups according to the Indonesian soil classification: Red Yellow Mediterranean soil, Latosol, Red Yellow Podzolic soil, and Lateritic soil. Podzolic soil, found on acidic volcanic tuff in Lampung, Indonesia, can be classified into Oxic Dystropepts, Sumbritropepts, Tropohumults, and Paleodults (Buurman, 1980). They are marginal soils that have many problems. Their characteristics are their low pH and low organic matter (Notohadiprawiro, 2006; Paiman, 2010), poor nutrients (Paiman, 2010; Sarno et al., 2004), high aluminum (Al) content and low base saturation (Notohadiprawiro, 2006), and low cation exchange capacity and sensitivity to erosion (Buurman, 1980; Sarno et al., 2004). Such problems in red soils have commonly been improved by the application of compost / organic matter, dolomite, *etc*.

Compost is derived from organic matter that has been decomposed and is relatively stable due to aerobic microbial degradation (Adugna, 2016). Compost is very important for improving soil fertility and for helping to increase plant productivity (Bouajila, 2011). It is rich in nutrients and organic matter (Sarwar et al., 2008). Many factors are affected by the provision of compost in the soil, including the enhancement of nutrient levels, as it contains N, P, K, Ca, Mg, and S. Compost is rich in alkaline cations, and thus, also has a liming effect that can increase the soil pH (Valarini, 2009).

Dolomite is limestone which is commonly applied to increase the soil pH (Peters et al., 1996). It is used not only for liming, but also as fertilizer due to the Ca and Mg elements contained in it which are needed to improve soil fertility and increase plant productivity (Mite et al., 2010). An increase in pH due to dolomite application also increases the availability of nutrients and can reduce the aluminum in the soil. This is a positive influence because it can reduce the effects of Al toxicity which can interfere with plant growth (Upjohn, 2005). The applications of compost and dolomite will affect the patterns of the essential nutrient availability in marginal soils.

PT Great Giant Pineapple (hereafter PT GGP) is a pineapple plantation located in Lampung, Southern Sumatra whose soil types include red-yellow podzolics (Komariah et al., 2008; Cahyono et al., 2018; Cahyono et al., 2019). These soils have a low base saturation value (<35%), very high acidity (pH<4.5), low cation exchange capacity, and high Al saturation. The nutrient content is generally low because nutrient leaching is very intensive. On the other hand, the organic matter content is low because the decomposition process runs fast and causes partial erosion. The low soil pH and low availability of potassium (K), magnesium (Mg), and calcium (Ca) are the greatest constraints in most acid upland soils (Prasetyo and Suriadikarta, 2006)

To overcome these soil constraint problems, the soil is improved by liming and the application of organic matter. Dolomite is commonly used for liming, because it can also raise the Ca, Mg, and base saturation in addition to increasing the soil pH. Compost can be used to increase the organic matter in the soil. Compost is the product of the decomposition process of organic matter that has been sanitized; it is very useful for improving the soil properties (Cahyono et al., 2019).

On pineapple plantations, the soil fertility is usually monitored before soil tillage, especially the soil pH and nutrient availability. It is very important to determine the amount of lime to be applied. Land preparation for pineapple plants takes approximately three months or 12 weeks depending on the readiness of the land. Compost is also applied during land preparation to improve the physical, chemical, and biological properties of the soil. After the land preparation, soil amendment, and seedling preparation, the soil is resampled to determine the nutrient content.

As background information, it is very important to determine the correct doses of dolomite and compost application for controlling the soil pH that can increase the availability of nutrients and can reduce the aluminum toxicity in the soil. The aim of this study is to evaluate the effects of dolomite and compost applications on the increase in soil pH, the availability of nutrients, and the decrease in exchangeable aluminum in the soil as well as the relationship between the soil pH and the Ca, Mg, K, Na, and Al contents.

Materials and Methods

Materials

This experiment was conducted at the Research and Development Department (R&D Dept.) PT GGP, Lampung, Indonesia (about 46 meters from sea level with coordinate of $4^0$49’27’’S and $105^0$13’55’’E), along 5 months, from February to July 2016. The texture of the soil is sandy clay with particle sizes of 52.4 % sand, 2.6 % silt and 45.0 % clay. The nutrient content in the soil and pH are shown in Table 16.

Table 16. Characteristic of soil and compost

Properties	Initial soil	Compost
pH	4.26	7.29
Total C (wt %)	1.32	20.38
Total N (wt %)	0.15	1.73
C/N ratio	8.80	11.78
P (g kg^{-1})	0.02	2.59
K (g kg^{-1})	0.08	18.00
Ca (g kg^{-1})	0.08	20.79
Mg (g kg^{-1})	0.03	5.45

The compost was from Compost Plant in PT GGP, obtained through a composting process of about 1 month from cow dung, bromelain waste and chopping bamboo. The nutrient content of compost are shown in Table 16. The Liming material used dolomite with containing 32.0 % CaO and 18.0 % MgO and particle size distribution 57 % of 60 mesh sieve.

Figure 15. Materials of Experiment

Experimental design

The experiment used a factorial completely randomized design with two factors and three replications. The first factor of compost dose and a second factor of dolomite dose. The treatmentss of compost used are: no compost (C0), compost 50 t ha^{-1} (C50), compost 100 t ha^{-1} (C100). The treatments of dolomite used are: no dolomite (D0), dolomite 1 t ha^{-1} (D1), dolomite 2 t ha^{-1} (D2), dolomite 3 t ha^{-1} (D3), dolomite 4 t ha^{-1} (D4) and dolomite 5 t ha^{-1} (D5), The total combinations are eighteen. Detailed treatment and abbreviation are presented in Table 17.

Table 17. Treatment detail with abbreviation

Treatment	Abbreviation
No compost, no dolomite	C0D0
No compost, dolomite 1 ton ha^{-1}	C0D1
No compost, dolomite 2 ton ha^{-1}	C0D2
No compost, dolomite 3 ton ha^{-1}	C0D3
No compost, dolomite 4 ton ha^{-1}	C0D4
No compost, dolomite 5 ton ha^{-1}	C0D5
Compost 50 ton ha^{-1}, no dolomite	C50D0
Compost 50 ton ha^{-1}, dolomite 1 ton ha^{-1}	C50D1
Compost 50 ton ha^{-1}, dolomite 2 ton ha^{-1}	C50D2
Compost 50 ton ha^{-1}, dolomite 3 ton ha^{-1}	C50D3
Compost 50 ton ha^{-1}, dolomite 4 ton ha^{-1}	C50D4
Compost 50 ton ha^{-1}, dolomite 5 ton ha^{-1}	C50D5
Compost 100 ton ha^{-1}, no dolomite	C100D0
Compost 100 ton ha^{-1}, dolomite 1 ton ha^{-1}	C100D1
Compost 100 ton ha^{-1}, dolomite 2 ton ha^{-1}	C100D2
Compost 100 ton ha^{-1}, dolomite 3 ton ha^{-1}	C100D3
Compost 100 ton ha^{-1}, dolomite 4 ton ha^{-1}	C100D4
Compost 100 ton ha^{-1}, dolomite 5 ton ha^{-1}	C100D5

Methods

Take soil samples before the soil added to polybag (15kg). Add compost according the treatment. For dose of 50 t ha^{-1} (bulk density of the soil: 1.2 g cm^{-3} and root depth: 20 cm), equivalent with 312.50 gram per polybag per 15 kg of soil and for dose of 100 t ha^{-1} equivalent with 625 gram per polybag per 15 kg of soil. Add dolomite according the treatment: 1 t ha^{-1} equivalent with 6.25 g/polybag/15 kg of soil, 2 t ha^{-1} equivalent with 12.50 g/polybag/15 kg of soil, 3 t ha^{-1} equivalent with 18.75 g/polybag/15 kg of soil, 4 t ha^{-1} equivalent with 25.00 g/polybag/15 kg of soil and 5 t ha^{-1} equivalent with 31.25 g/polybag/15 kg of soil. Mixed dolomite and compost in the polybag until homogeny and keep soil humidity (Figure 16).

Figure 16. Mixing the soil, dolomite and compost according the treatment

Soil Sampling and Analysis

Soil sampling and analysis were conducted first before treatment, and the second at 12 weeks after treatment to know the changes of soil chemical properties. Soil properties observation consist of: (1) The pH was determined by using pH Meter-Mettler Toledo, (2) Analysis of K, Ca and Mg was determined by using extraction with ammonium acetic pH 7 and reading with Atomic Absorption Spectrofotometry (AAS)-GBC. Analysis of Al was determined by volumetric method.

Statistical Analysis

All the data collected from the three replication were subjected to the analysis of variance (ANOVA) using Tukey Test and 95.0 % confidence to determine differences among treatments.

Result and Discussion

Effects of Soil Amendment on Soil pH

Dolomite is ground limestone and the most common liming material (Mamo et.al., 2009) . It is seen in Figure 1 that increasing the dolomite dose can significantly increase the soil pH 12 weeks after the dolomite application. The control (D0) with no application of dolomite has the lowest soil pH, while the dolomite dose of 5 t ha^{-1} (D5) shows the highest pH among all treatments at the same level of compost dose. Therefore, the soil pH has a clear tendency to increase with increasing dolomite dose applications.

Compost applications also increase the soil pH because the pH value of compost is higher (pH 7.29) than that of the initial soil (pH 4.26), as seen in Table 16. The soil pH when applying the compost dose of 100 t ha^{-1} (C100) is the highest, while the soil pH under the no compost application (C0) is the lowest at the same level of dolomite dose. It was also stated in a previous research (Valarini, 2009), that applications of compost, based on cow manure and wheat straw at doses of 20 ton ha^{-1} and 30 ton ha^{-1}, respectively, increase the soil pH.

Furthermore, the simultaneous application of compost and dolomite can increase the soil pH. Figure 1 shows that the highest soil pH was achieved with the treatment of the compost dose of 100 t ha^{-1} and the dolomite dose of 5 t ha^{-1}, and that the combination of the two treatments produced the highest soil pH and was significantly different from the other treatments. The effects of the interaction of compost and dolomite are presented in the table at the bottom of Figure 17.

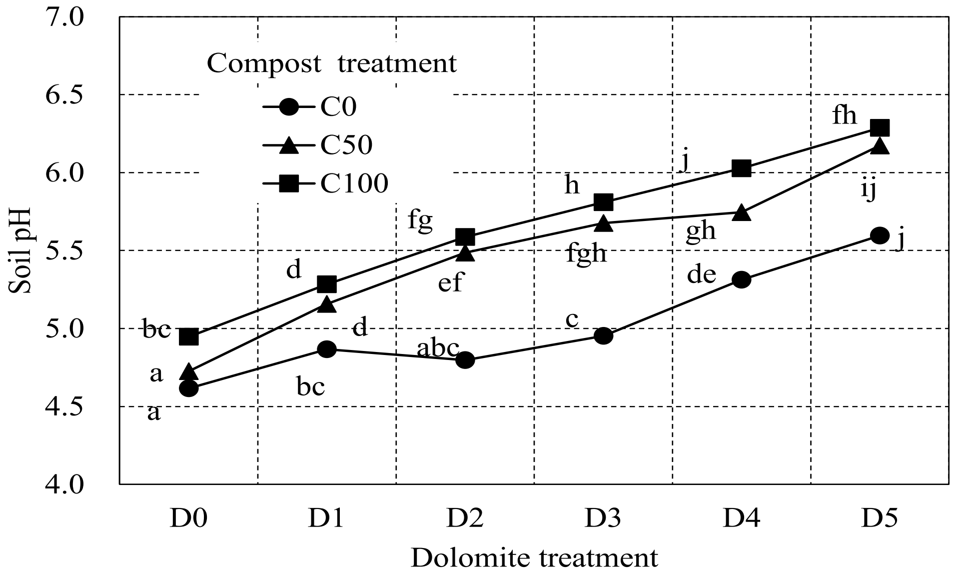

Figure 17. Effects of dolomite and compost application on soil pH 12 weeks after treatment

Note: Mean followed by the same letter is not significantly different at α=0.05

The soil pH increases significantly from 4.62 (a) to 5.60 (fh) by applying up to 5 tons ha^{-1} of dolomite without compost amendments, while the soil pH increases from 4.62 (a) to 4.95 (bc) by applying 50 ton ha^{-1} of compost without dolomite. In other words, it was proven that the effect of dolomite is more dominant than that of compost in increasing the soil pH.

When dolomite ($CaMg(CO_3)_2$ is put into the soil, it will reduce the H^+ by the following simple reactions (Mansur and Koko, 2000):

1. $CaMg(CO_3)_2 + 2H^+ \Leftrightarrow Mg^{2+} + CaCO_3 + CO_2 + H_2O$

2. $CaCO_3 + CO_2 + H_2O \Leftrightarrow Ca^{2+} + HCO_3^- 3OH^-$

3. $Al^{3+} + 3 OH^- \Leftrightarrow Al(OH)_3$ (settles)

The chemical reaction of dolomite in soil can cause the release of Mg, Ca, and OH^-.Bayer *et al.* (2001) stated that decomposed organic material will produce OH^- ions which can neutralize the H^+ ion activity. Thus, applying compost to soil can increase the soil pH. The application of 5 ton ha^{-1} of dolomite can increase the pH by 1.09 points (Cahyono, 2019). Moreover, the application of 50 ton ha of compost can increase the pH by 0.9 points (Cahyono, 2020). The combined application of 15 ton ha of compost and 0.7 ton ha of dolomite can increase the pH by 0.77 points (Syahputra et al., 2015).

Effect of Soil pH on Nutrient Availability

Calcium (Ca) and (Mg) magnesium are base cations that decline with the increase in acidity. If the soil pH increases, the base cations also increase (Bolan et al., 2003).

The contents of Ca and Mg in the soil correlate well with the soil pH. Figure 18 shows a good agreement between the soil pH and the available Ca with R^2:0.702 12 weeks after the treatment. This means that the increase in the soil pH is affected by the applications of compost and dolomite, which can increase the Ca availability. It was stated by Adugna (2016) that the soil pH affects the nutrient availability in the soil. The application of compost has a liming effect that can enrich the Mg, Ca, and K cations resulting from the mineralization of the organic material.

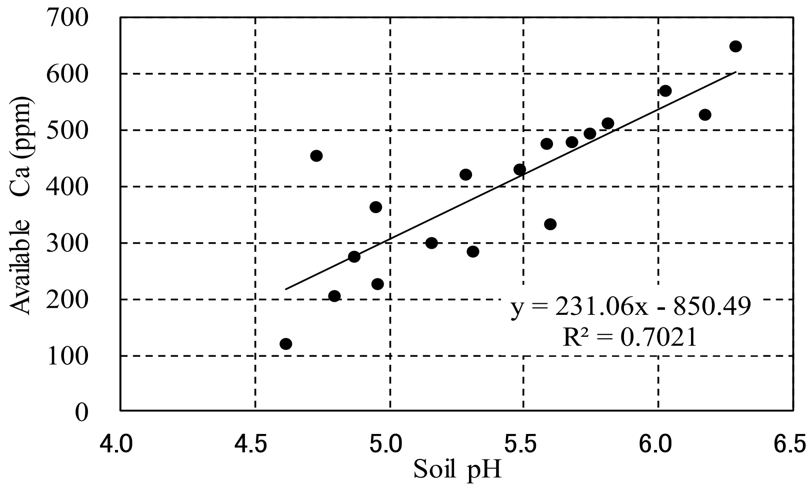

Figure 18. Effect of soil pH on available calcium 12 weeks after treatment

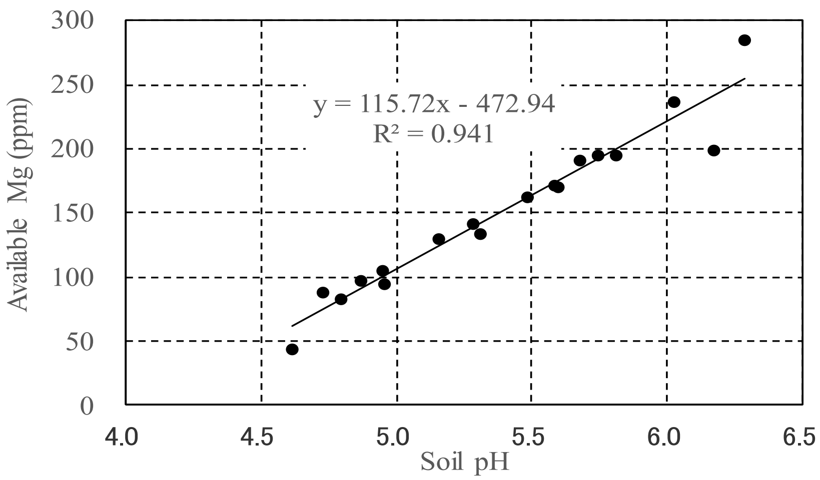

Figure 19. Effect of soil pH on available magnesium 12 weeks after treatment

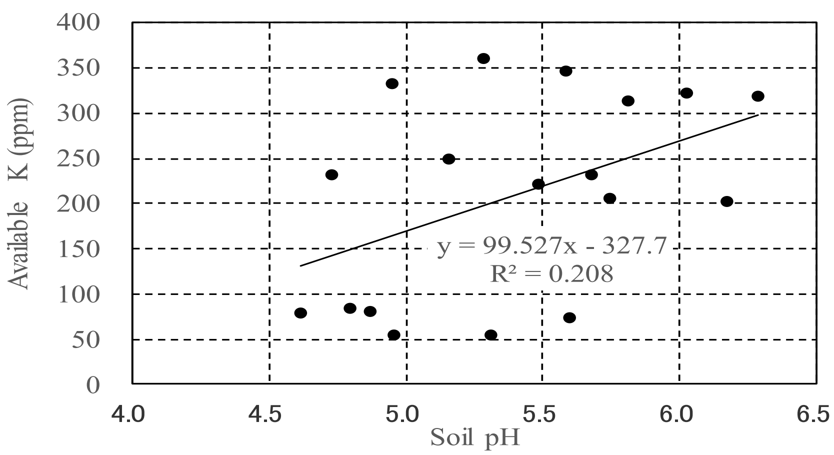

Figure 20. Effect of soil pH on available kalium 12 weeks after treatment

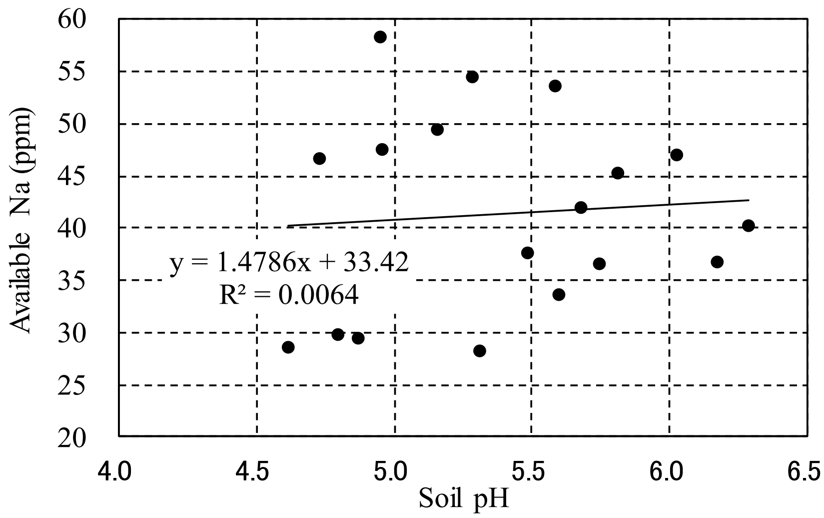

Figure 21. Effect of soil pH on available natrium 12 weeks after treatment

The available Mg content in the soil also increases significantly with the increase in the soil pH 12 weeks after the treatment. Figure 19 shows a good correlation between the soil pH and the available Mg with R^2:0.941. This means that the soil pH is increased by the application of compost and dolomite, which can also increase the Mg availability. This is in line with the statement by Valarini et al. (2009), namely, that increasing the pH level due to the addition of compost to the soil will also increase the exchangeable bases.

The available K and Na in the soil do not correlate well with the increase in the soil pH. Figure 20 and Figure 21 shows a low correlation between the soil pH and the available K and Na with R^2:0.208 and 0.0064, respectively, 12 weeks after the treatment. The increasing soil pH is affected by the applications of compost and dolomite, which do not increase the available K and Na.

The above results led to the soil pH being strongly affected by the application of dolomite, which consisted of calcium and magnesium compounds, but did not include K or Na. This is the reason why the availability of Ca and Mg was affected by the pH in soil, but not the K or Na.

Pattern of Exchangeable Aluminum Affected by Soil pH

Aluminum (Al) is the third most abundant element in the Earth's crust after oxygen and silicon, and is universally present in soil. Al is harmless because it is stably retained by soil minerals in neutral soil, but it dilutes into Al^{3+} ions in acidic soil (pH 5.5 or less). Even in trace amounts, it rapidly inhibits plant root elongation.

Table 18. Results of multiple regression analysis

objective	coefficient			p-value			r	r^2
	intersept	compost	dolomite	intersept	compost	dolomite		
pH	4.49	0.00633	0.236	1.75E-19	1.43E-06	4.52E-09	0.965	0.931
Ca	171	2.58	38.2	8.58E-05	3.81E-06	0.000542	0.906	0.822
Mg	43.3	0.850	26.1	0.000485	1.49E-06	6.29E-08	0.955	0.912
Na	36.8	0.170	-1.58	3.19E-09	0.000167	0.0725	0.809	0.655
K	93.1	2.61	-5.92	1.51E-08	3.96E-14	0.0219	0.990	0.980
Al	0.753	-0.00401	-0.123	8.15E-07	0.00188	0.000229	0.845	0.713

r:multiple correlation coefficient

The aluminum (Al) in the soil has a good correlation with the soil pH. The exchangeable Al in the soil decreases significantly and correlates well with the increase in the soil pH. Figure 3 shows that the correlation between the soil pH and the exchangeable Al is very fitting to the quadratic curve with R^2:0.883. This means that the increasing soil pH is affected by the applications of compost and dolomite, which can decrease the aluminum availability to a soil pH of 5.5. Dolomite, as lime, can reduce the Al and metal element (Sawyer J.E.,2020) Increasing the soil pH can decrease the Al (Li W. and Johnson C.E., 2016) Prasetyo and Suriadikarta (2006) also stated that there was a good relationship between the increase in pH due to liming and the Al content in the soil.

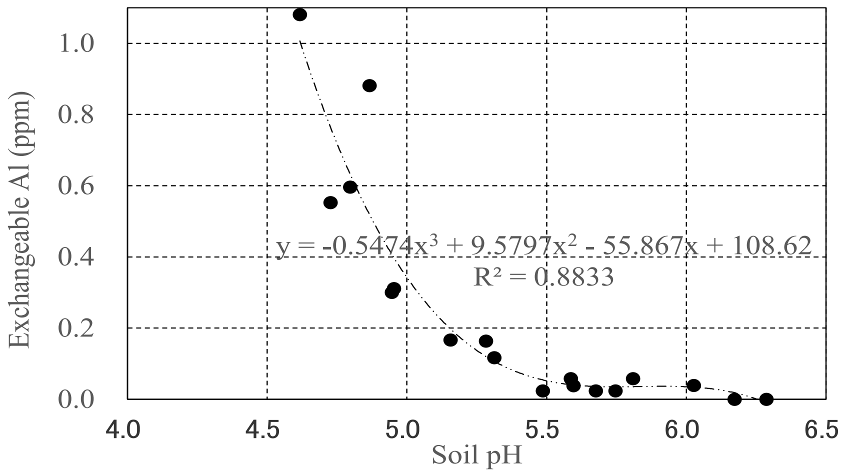

Figure 22. Effect of soil pH on exchangeable aluminum (Al) weeks after treatment

Effect of Compost and Dolomite Application on Nutrient Availability

A multiple regression analysis was carried out to evaluate the effect of compost and dolomite applications on the soil chemical properties.

As for the regression analysis, the chemical properties of the soil (pH, Ca, Mg, Na, K, and Al) were used as the response variables, and the applications of compost and dolomite were used as the explanatory variables. Table 18 presents the results of the multiple regression analysis. The results indicate that:

The soil pH is closely related to both the compost (p-value: $1.43*10^{-06}<0.01$) and the dolomite (p-value: $4.52*10^{-09}<0.01$) applications, which means that dolomite has a greater effect on the soil pH than compost.

The soil pH can be predicted with high accuracy (R^2=0.931, significant F-value=$1.98*10^{-9}$) by the multiple regression equation as follows:

$$\text{Soil pH} = 4.49+0.00633\times\text{compost (t/ha)}+0.236\times \text{dolomite (t/ha)} \qquad (1)$$

Here, the value of the intercept (4.49) is considered as the soil pH of the initial condition before the applications of compost and dolomite.

The available Mg is also closely related to both the compost (p-value: $1.49*10^{-06}<0.01$) and the dolomite (p-value: $6.29*10^{-08}<0.01$) applications, which means that the dolomite application increases the Mg more than the compost application.

The available Ca is more strongly influenced by the compost (p-value: $3.81*10^{-06}<0.01$) than by the dolomite (p-value: $0.000542<0.01$) due to the fact that compost can supply a higher Ca element (20.8 g kg^{-1}) than dolomite.

The application of 5 ton ha^{-1} of dolomite can increase K by 14.7 ppm, Ca by 315.5 ppm, and Mg by 148.9 ppm (Cahyono, 2019). Moreover, the application of 50 ton ha of compost can increase K by 80 ppm, Ca by 580 ppm, and Mg by 150 ppm (Cahyono, 2020).

On the other hand, the compost application significantly increases the available Na (p-value: $0.000167<0.01$) and K (p-value: $3.96*10^{-14}<0.01$), but the dolomite application has no significant effect on the available Na (p-value: $0.0725>0.01$) and available K (p-value: $0.0219>0.01$). These results suggest that the available Na and K can be supplied by compost applications, but are not affected by the soil pH (Figure 21 and Figure 22) which is increased by dolomite applications.

The exchangeable Al in the soil decreases with the increase in compost and dolomite applications due to the value of the coefficient being less than 0 (compost: -0.00401 and dolomite: -0.213), and is more significantly influenced by dolomite (p-value: 0.000229) compared to compost (p-value: 0.00188). The multiple correlation coefficient (r) has the lowest value (0.845) among all the soil chemical properties, except for Na, due to the limitation of the linear equation adopted in this analysis.

Finally, the following effects can be clarified from the results of the multiple regression analysis, as shown in Table 18. The contents of Ca and Mg cations increase by 38.2 and 26.1

ppm by each application of 1 t/ha of dolomite, respectively, but Na and K do not increase because dolomite does not contain these two cations since its chemical formula is $CaMg(CO_3)_2$. On the other hand, each application of 1 t/ha of compost can increase the contents of Ca, Mg, Na, and K cations by 2.58, 0.85, 0.17, and 2.61 ppm, respectively.

Conclusion

The application of dolomite and compost, respectively, can significantly increase the soil pH. The combination of compost and dolomite can increase the soil pH even more significantly. The pattern of nutrient changes in the soil, such as Ca and Mg, showed a good linear correlation with the changes in the soil pH, but K and Na did not show a good relationship. The exchangeable aluminum in the soil showed a good quadratic correlation with the soil pH for red acid soils.

Furthermore, the available Ca, Na, and K were more significantly affected by the application of compost than by that of dolomite. Contrarily, the available Mg and Al were more significantly affected by the application of dolomite than compost. It can be concluded from this experiment that the best combination of compost and dolomite applications for improving the soil pH, base cations, and decreasing Al toxicity is a 100 t/ha dose of compost and a 5 t/ha dose of dolomite. This is due to the fact that the soil pH (6.303), Ca (620 ppm), Mg (258.8 ppm), Na (45.90 ppm), K (324.5 ppm), and Al (0 ppm) can be attained by this combination of compost and dolomite based on the results of a multiple regression analysis, all of which are appropriate values for pineapple plants.

CHAPTER V

GENERAL CONCLUSION

Based on finding in the first research, it was seen in the first research, that the application of compost could not increase the nutrient uptake in the leaves of pineapples, but the foliar fertilizer application was effective enough. The pineapple yield was seen to increase with the application of a compost dose of 50 t ha^{-1} compared with the control, but the yield was no different from that with a compost dose of 25 t ha^{-1}. However, the application of a compost dose of 50 t ha^{-1} consistently produced a higher yield compared to the other treatments except for K25P60 treatment. The application of the compost dose of 25 t ha^{-1} enabled a reduction in the use of chemical fertilizer applied by foliar spray by 40% with no loss in yield.

The second research showed that the application of dolomite was seen to increase the soil pH significantly and in different ways. Increasing the soil pH increased the potassium (K), calcium (Ca) and magnesium (Mg) in the soil and decreased the iron (Fe) considerably. Increasing those soil chemicals and decreasing the iron in the soil were found to improve the growth of the pineapple. In particular, the leaf area of the pineapple plant increased significantly. The other parameters also increased, but not significantly.

The third research showed that the application of dolomite as a liming can increase soil pH. Application of compost also can increase soil pH significantly different. Combination of compost and dolomite can increase soil pH significantly different. The pattern of nutrient changes in soil such as Ca and Mg show a good linear correlation with changes of soil pH but for K does not show a good relationship. Whereas for Exchangeable aluminum in the soil show a good quadratic correlation with soil pH on red acid soils.

Overall, it can be concluded that the application of compost as organic matter can improve soil fertility from both chemical and physical aspects of soil. This improvement in soil properties has a direct result in improving the growth and production of pineapple plants. Combining compost and inorganic fertilizers with the right dosage will improve the growth and production of pineapple plants. Apart from providing organic compost, the second strategy to improve red acid soil is lime. Dolomite as lime which is very commonly used for agriculture is very effective for increasing soil pH. This increase in pH is very important in increasing the availability of secondary macro elements that are needed by plants. In addition, increasing soil pH can reduce the toxicity of micro elements. The combination of compost and dolomite has been shown to be effective in increasing soil pH and organic matter, both of which are major limiting factors in red acid soil.

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